EVALUATION OF MODIFIED KLEINERT'S TRACTION EARLY MOBILISATION REGIMEN FOR FLEXOR TENDON INJURIES IN ZONE V

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CERTIFICATE

This is to certify that the dissertation titled **"EVALUATION OF MODIFIED KLEINERT'S TRACTION EARLY MOBILISATION REGIMEN FOR FLEXOR TENDON INJURIES IN ZONE V"** is a bonafide work done by **Dr. PRAVEEN KUMAR P.M.** in partial fulfillment of the requirements for **M.Ch. (Plastic Surgery) Branch – III** Examination of The Tamil Nadu Dr. M.G.R. Medical University to be held in February 2006. The period of study was from July 2003 to August 2005.

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INTRODUCTION

***"One of the most baffling problems in hand surgery is to restore normal function to a finger in which the tendons have been injured*"** – wrote Sterling Bunnell in his classic book on Surgery of the Hand.

Sixty years hence, there has been much improvement in the management of tendon injuries and is an evolving field of hand surgery.

There is now an emphasis on primary tendon repair and early mobilization for optimal results whenever possible. The early mobilisation protocols for rehabilitation after flexor tendon repair have been evolved by better understanding of biomechanics and healing potential of tendons.

Flexor tendon injuries occur mostly in young individuals in the prime of their lives, resulting in significant socioeconomic impact. Hence restoration of a functional hand after flexor tendon repair by the plastic surgeon is of paramount importance to the patients.

AIM OF STUDY

This study is done to evaluate the functional outcome of **Modified Kleinert's Rubber band traction as early mobilisation regime** following flexor tendon repairs in Zone V in our setup in terms of :

- **Digital range of motion**
- **Differential digital tendon excursion**.

HISTORICAL ASPECTS OF FLEXOR TENDON REPAIR

The first person to write about the suture of divided tendons was the tenth century Arab surgeon **Avicenna**, who taught that a cut or ruptured tendon must be sewn together. Avicenna's writings ran counter to the medical teaching of the time that nerves and tendons were identical tissue and that handling this tissue could cause convulsions or gangrene. This particular assumption was attributed to **Galen**, the second century Greek physician, who described nerves entering each muscle. Galen noted that the muscles ended with a whitish cord (the tendon), which he thought was the termination of the nerve bundles. Galen created a confusing picture because physicians of that time believed that anatomists, including Galen himself had accurately described the differential anatomy of nerve, tendon, and ligament. Despite anatomical evidence, Galen’s warnings against tendon suture prevailed.

Little was written about tendon repair again until the seventeenth century, when a few examples of successful tendon repair were published. In 1665 **Moinchen** wrote about tenorrhaphy in humans. Others duplicated the operation in animals. According to **Gratz, LaVauguin** attempted to define the technique and described acute and secondary tendon repair. **LaVauguin** reported that incompletely cut tendons should be completely divided and sutured; otherwise, "acute pain, convulsions, and sometimes gangrene will ensue." To avoid penetrating the surface of a tendon, techniques were developed of tying encircling sutures about each end of a cut tendon and then tying these sutures together to bring the cut surfaces into apposition.

Well into the early eighteenth century, however, surgeons were still reluctant to advise tenorrhaphy until the celebrated experimental work of **Haller** in 1752. **Haller** showed conclusively that tendons were "insensible" and that repair by suture would not be followed by dire consequences. Objection to tenorrhaphy declined thereafter.

Waterman, in a review article, credits **Missa** with performing the first tendon graft. **Missa**, in 1770, described a situation in which the extensor tendon of the middle finger was severed and could not be sutured. He "grafted" the distal end on the tendon of the ring finger. This suture actually represented a transfer rather than a tendon graft. Others, including **Velpeau** in 1839 and **Malgagni** in 1862, supported the concept that severed tendons could be sutured to adjacent intact tendons.

It was mid nineteenth century when **Syme** reported several successful cases of flexor tendon repair.

In 1881 **Nicoladoni** presented a case in which he had transferred the peroneal tendons to the Achilles tendon for paralytic talipes calcaneus. Initially successful, this procedure ultimately failed because of separation of the juncture. Although this was the first published report of using this technique for paralytic clubfoot, the procedure of tendon transfer had been performed long before, most notably by **Missa** and also by **Velpeau** and **Malgagni**. Waterman writes that many surgical innovations are foreshadowed much earlier than their latest appearance, that is, they have been "discovered, forgotten and rediscovered." Since 1881 and the introduction of "grafting" in poliomyelitis, no fewer than six physicians have proposed this operation as a new type of surgical intervention .

Surgeons became discouraged at the difficulty in obtaining functional results after a tendon transfer: **Nicoladoni**, despite a long and productive surgical career, never performed the procedure again. In Poland **Drobnik** reported the first successful series of tendon transfers in 1892; his case number five was of particular interest because it was the first reported example of tendon transfer for infantile paralysis in the upper extremity this was followed by the reports of **Goldthwait** and Parrish in the United States. **Franke** applied the method to infantile spastic paralysis of cerebral origin and also was the first to report tendon transfer for the treatment of radial nerve paralysis.

The actual graft of a free tendon segment, in contrast to the transfer of a tendon, was first reported by **Heuck** in 1882. According to **Adamson** and **Wilson**, **Heuck** repaired a defect in the long thumb. extensor, accidentally created at surgery, by suturing the tendon segment back into its original place. Others reported good results with the use of animal tendons as graft material to repair tendon injuries in humans.

Pulvertaft cites as the first tendon graft the one performed by **Robson** in 1889, in which he used 11 cm of flexor tendon from a damaged long finger to replace the extensor tendon in the index finger. In 1902 **Mainzer** used autogenous tendon grafts from paralyzed tendons to lengthen the motor tendon in transfer procedures.

Dissatisfaction with the results obtained in tendon surgery was still prevalent. Aside from sepsis, the problem of adhesion formation, which interfered with effective gliding, troubled tendon surgeons. The gliding mechanism was studied by **Codavilla**, who stressed that the tendon sheath of the paralyzed muscle should be preserved for the transferred tendon, thereby reducing the possibility of adhesion formation. **Biesalski** also studied the adhesion problem. He applied **Codavilla's** principles and published the results in 1910.

Lange, who had much clinical experience in tendon work, was involved during this period in a professional dispute with **Vulpius**. **Vulpius** believed that the transfer did better when sutured to the paralyzed tendon, while Lange held that the insertion should be directly to the periosteum. Lange even added silk strands to the transfer, enabling him to obtain the length necessary to accomplish the desired result. Unfortunately, in many instances the results were reduced by adhesion formation to the silk tendon elongation. Lange assigned this problem to his two American assistants, **Mayer** and **Henze**; their subsequent study confirmed **Codavilla's** and **Biesalski's** work . **Mayer** was then invited to work in **Biesalski's** clinic, and from his research evolved the “physiological method of tendon transplantation”. These rules most of them still applicable, stress the importance in tendon surgery of atraumatic technique, the need for good gliding planes and adequate tendon motors, and selection of proper tension in a reconstructed tendon system. Emphasis was also placed on good postoperative care by the operating surgeon. The rules for tendon transplantation engendered great respect for the vascular supply of the tendon. Early protected motion, graded exercises, and protective splinting were recommended.

Lexer in 1912 published the first series of reports on free flexor tendon grafts. **Sterling Bunnell** in 1918 wrote of his early concepts of flexor tendon surgery. He was influenced by the teachings of Mayer and had adopted Mayer’s methods of tendon surgery in the hand. The importance of gentle handling of these delicate tissues was noted by **Bunnell**, since trauma influenced the formation of adhesions. To prevent the development of joint contractures, the lateral longitudinal incision in the finger was developed. **Bunnell** stressed the importance of preserving the flexor pulleys to prevent the spanning of the joint angles "like the string in a bow." When the pulleys were not preservable he suggested the use of a foot tendon graft with an intact sheath.

Bunnell recommended tendon grafts in old cases of trauma or infection because this technique was more likely to be successful. He wrote about the possible need for tenolysis as a secondary procedure to release limiting adhesions. By the 1940s, **Bunnell** had acquired great clinical experience and had studied many aspects of hand surgery. His textbook, first published in 1944, became a cornerstone on which the subspecialty of hand surgery was built.

Thus the modern era of tendon surgery emerged. Many physicians contributed to the development of knowledge aimed at improving the results of treatment for tendons ravaged by injury. Many of the problems that confronted earlier surgeons in this field are still to be solved. In 1928 **Gratz** stated: "The operations developed, finally reaching the point of perfection which today aseptic surgery has allowed it to attain.

The work of pioneer surgeons contributed significantly to current practice and results.

Claude Verdan described zones of flexor and extensor tendons in hand to standardise and document flexor tendon injuries.

Mason, Kessler, Allen were instrumental in devising new techniques of flexor tendon suturing.

Harold Kleinert was notable for his research on early mobilisation protocol after tendon repair and achieved satisfactory results in Zone II lacerations, once termed ‘No-Man’s land’ by **Bunnell**.

The works of **Lundborg, Rank, Schepel, Potenza** and **Umeda** were the milestones for describing intrinsic healing mechanism of tendons with less adhesion formation and paved way for early mobilisation of tendon repairs.

REVIEW OF LITERATURE

There are only moderate number of articles on flexor tendon injuries in Zone V. Stated below are the abstracts from literature pertaining to my study.

- **Charles L Puckett et al**[1] in 1984 published the results of treatment of extensive volar wrist lacerations (Zone V injuries) in 38 wrists and defined spaghetti wrist injury as those having atleast three completely transected structures. They used Kleinert's type protected early mobilisation regime for tendon repairs in Zone V and achieved good to excellent results in 97% of patients. No tendon ruptures were encountered and tenolysis was not required for any of the cases.

- **Slattery & McGrouther**[18] in 1984 devised a modification of Kleinert's splint incorporating a pulley at the distal palmar crease like the one devised at Brookes Army Hospital to facilitate improved passive flexion at the distal interphalangeal (DIP) joint by rubber band traction.

- **Mark Edinburgh et al**[6] in 1987 published the results of early post operative mobilisation of 99 flexor tendon injuries in all zones of flexor tendons using a modification of Kleinert's technique. The modification consists of incorporation of a Steinman's Pin in distal palm attached to the dorsal POP slab to act as a pulley to increase the passive flexion at distal interphalangeal (DIP) joint by rubber band traction. Both FDP and FDS were repaired in all cases and using this modified Kleinert's splint in 20 digits of Zone V injuries, the functional outcome as assessed by Buck-Gramcko system was excellent in 35%, good in

20% , fair in 25% and poor in 20%.

- **Knight S.L.**[12] in 1987 devised a modification of Kleinert's dynamic splint in which the rubber band is looped around the dorsum of the hand, rather than attached to the volar aspect of the wrist or forearm. This alters the direction of traction so that the interphalangeal joints are more effectively mobilised. This modified splint was used in early mobilisation of 8 cases of flexor tendon injures in Zone II and Zone III and achieved excellent results in 7 cases and encountered 1 tendon rupture.

- **Raymond J. Stefanich et al**[17] in 1992 published the results of 23 patients with flexor tendon laceration in Zone V rehabilitated by the Kleinert's protocol at an average of 46 months after trauma. 16 out of 23 patients regained full digital flexion. Independent FDP / FDS actions were present in only 7 patients. Extension loss averaged 25% at wrist and 10% in each digit. Complications included two tendon ruptures, proximal interphalangeal joint hyperextenion in the presence of an unrepaired flexor digitorum superficialis and limited tendon motion in two patients after poor compliance in therapy. Tenolysis was needed in 4 patients out of 23.

- **Yii N.W., Urban et al**[21] in 1998 published a prospective study of 52 patients with flexor tendon repairs in Zone V and rehabilitated with controlled active motion (Active extension – active flexion) regimen of mobilisation. Of the 161 fingers with division of one or both flexor tendons, 90% achieved good or excellent results of digital range of motion. Only 66% exhibited independent FDS & FDP action. Multivariate analysis showed the presence of spaghetti wrist injury to have a significant adverse effect on the recovery of the independent FDS action but not on recovery of digital range of motion.

SURGICAL ASPECTS OF FLEXOR TENDONS

FLEXOR TENDON ANATOMY

The anatomy of extrinsic flexor muscles and tendons is somewhat complex and must be thoroughly appreciated by all surgeons undertaking tendon repair of reconstruction. Although historic anatomic descriptions have largely stood the tests of time, recent investigations have added greatly to our understanding of origins, course, insertions and interrelationships of various components of flexor system.

The extrinsic flexor muscles of the forearm form a prominent mass on the medial side of the proximal half of forearm. The most superficial group is composed of Pronator teres (PT), Flexor carpi radialis (FCR), Flexor carpi ulnaris (FCU) and Palmaris longus (PL).

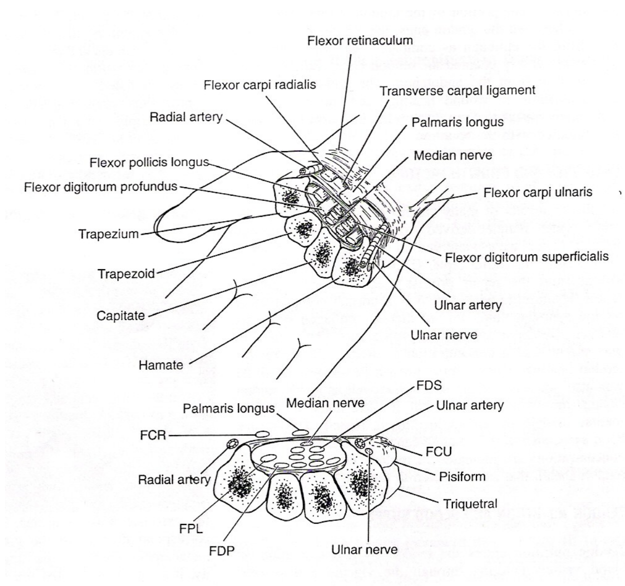
The intermediate group consists of Flexor digitorum superficialis (FDS), and the deep extrinsics are composed of Flexor digitorum profundus (FDP) and Flexor pollicis longus (FPL).

In distal forearm, extrinsic flexor tendon arise from flexor muscles. The most superficial group is composed of FCR, FCU, PL which act primarily as wrist flexors.

The intermediate group consists of the FDS, and the deepest group consists of FDP & FPL. The FDS tendon usually arise from single muscle bundles and act independently whereas the FDPs often have a common muscle origin for several tendons and produce simultaneous flexion of multiple digitis.

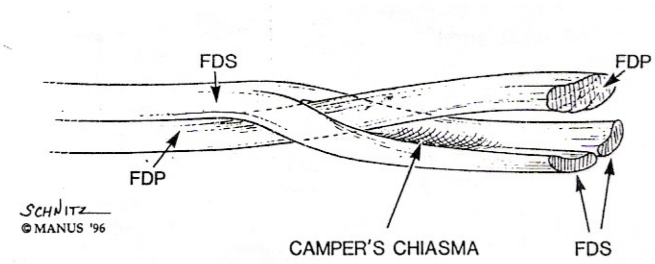
At the wrist, the nine long digital flexor tendons enter the carpal tunnel beneath the protective roof of transverse carpal ligament in company with the median nerve. In this canal, the common profundus tendon to the long, ring and small fingers divide into individual tendons that fan out distally and proceed toward the terminal phalanges of these digits.

FLEXOR TENDONS AT DISTAL FOREARM AND WRIST



At approximately the level of the distal palmar crease, the paired profundus and superficialis tendon to index, long, ring and small fingers and the FPL enter the individual flexor sheaths that house them through the remainder of their digital course. These sheaths with their predictable annular pulley arrangements not only serve as a protective housing for the flexor tendons but also provide a smooth gliding surface by virtue of their synovial living and an efficient mechanism to hold the tendon close to the digital bone and joints.

The FDS tendons lie on palmar side of the FDP tendons until they enter the AI entrance of digital sheath. Within the proximal sheath the FDS tendons divide into two flap slips that wrap obliquely around the lateral and dorsal aspects of the profundus tendon, rejoin dorsally by means of fibres referred to as Camper's chiasma and terminate as two slips that insert along the proximal half of the middle phalanx. The profundus tendons pass through the superficialis decussation to insert into the proximal aspect of the distal phalanx.

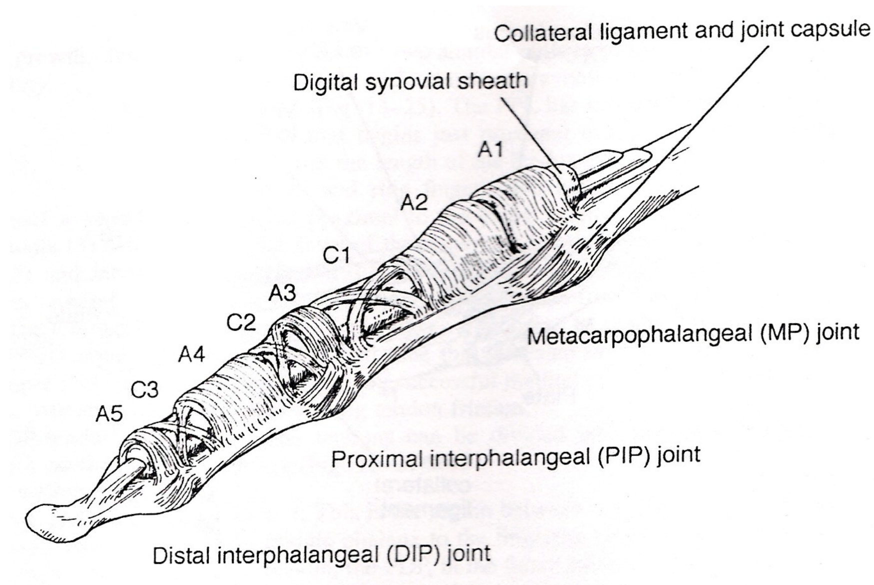


In the digits, the flexor tendons are enclosed in sheaths lined by visceral and parietal synovial layers between which is a layer of synovial fluid. The synovium is thin and well vascularised and at the level of metacarpophalangeal joints (MP), merge with the epitenon to form a cul –de-sac. The original descriptions of Doyle & Blythe as supplemented by the findings of Hunter et al. and Manske et al remain the accepted working sysem for most hand surgeons.

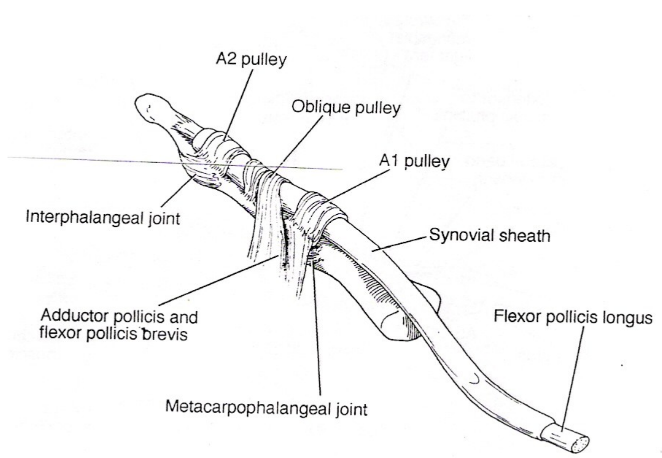
The annular pulleys A2 and A4 arise from periosteum of the proximal half of proximal phalanx and mid portion of middle phalanx respectively. A1, A3, A5 are joint pulleys arising successively from the palmar plates of MP, PIP, DIP joints. The palmar aponeurosis pulley is composed of transverse and vertical fibres of the palmar fascia and is clinically important when other proximal components of the sheath have been lost. The thin condensable cruciate sections of the sheath are the C1 between A2 & A3 pulleys, C2 between A3 & A4 pulleys and C3 between A4 and A5 pulleys, all of which collapse to permit the annular pulleys to approximate each other during digital flexion.

The flexor tendons are weakly attached to the sheath by fibrous mesenteries – the vincula.

Annular and cruciate pulleys of digital flexor tendons



Annular and oblique pulley of FPL

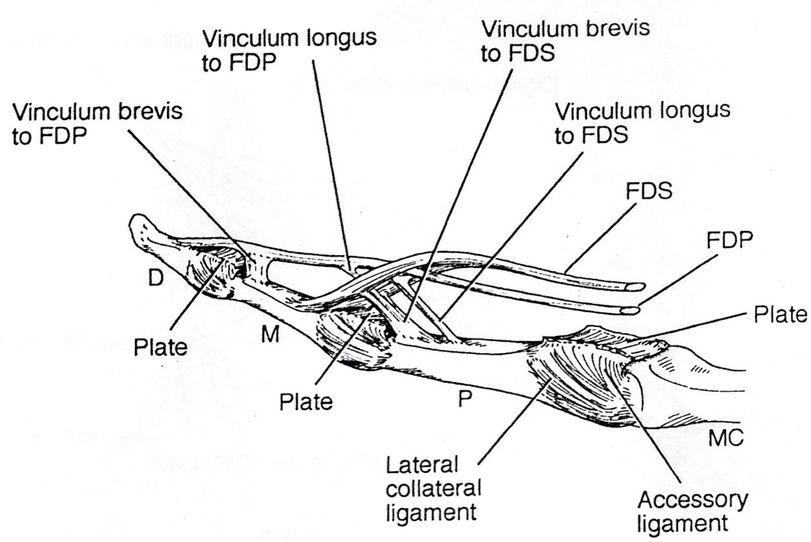


FLEXOR TENDON NUTRITION

Blood supply of flexor tendons is segmental in origin. In the extrasynovial areas, blood is derived from surrounding loose connective tissue or paratenon. This highly vascular tissue surrounds the tendons in the palm of hand and proximal to carpal tunnel.

Vascular perfusion of flexor tendons includes longitudinal vessels that enter in the palm and extend down intratendinous channels, vessels that enter at the level of proximal synovial fold in the palm, segmental branches from the paired digital arteries that enter in the tendon by means of the long and short vinculae and vessels that enter the FDS & FDP tendons at their osseous insertions.

Vincula Longa and Brevia of Digital Flexor Tendons



Internal vascularity of the tendon is primarily positioned in the septa of the endotenon separating the tendon fascicles.

The vascular supply of the tendon is mainly on the dorsal surface. The dorsal and lateral aspects of flexor tendons are relatively avascular. The volar aspect of the tendons is not completely devoid of blood vessels, but is served by transverse vascular loops from the major dorsal longitudinal vessels.

ROLE OF THE SYNOVIAL FLUID

There is increasing evidence that synovial fluid plays a major role in the nutrition of tendons within digital canal. The synovial fluid is produced by beaker cells in the membranous parts of the fibrosynovial sheath. These membranous portions of the sheath are located between the annular pulleys and are highly vascular, unlike the annular pulleys which are relatively devoid of vessels. The thin membranous portions of the tendon sheath are enforced by cruciate ligaments and are found over dorsal aspects of the joints. The synovial fluid is responsible for lubrication, which allows the tendons to glide within the sheath without friction.

It has now been demonstrated that tendon tissue that is deprived of its blood supply can survive, and injured tendon ends can actually unite when bathed in a synovial medium. Thus tenocytes can obtain their necessary nutrients exclusively from synovial fluid when the circulation is impaired.

Weber has shown the existence of synovial fluid pumping mechanism within flexor tendon sheath complex that aids the entire process of synovial nutrition of the tendon.

Examination with electron microscope reveals longitudinal valleys on the surface of tendon substance. These valleys appear to be continuous with conduits in the tendon substance. The fibro osseous pulleys have transverse ridges allowing a maximal contact area for synovial fluid with the surface of the tendons. Under the influence of tendon movements, fluorescein labelled cells in synovial fluid were seen to permeate deep into tendon tissue within several minutes.

This reinforces the concepts of restoration of early motion after flexor tendon repair, as the mechanical factor of tendon movements improves flow of synovial fluid into and within the tendon substance[15].

FLEXOR TENDON HEALING

It is now believed that tendons have both an intrinsic and an extrinsic capability of healing.

The process of tendon healing involves three overlapping phases

1) **Inflammatory phase** from 3 days to 5 days after repair

2) **Fibroblastic (or) collagen producing phase** that begins about 5 days and lasts 3-6 weeks.

3) **Remodelling (or) Maturation phase** that continues till 6-9 months.

During the inflammatory phase, the strength of repair is almost entirely what is imparted by suture itself with a moderate contribution from fibrin and clot between tendon ends. Strength increases rapidly during fibroblastic phase, which is characterised by synthesis of collagen and other components of extra cellular matrix (ECM) and proliferation of endothelial cells that form new capillaries. During remodelling or maturation phase, collagen synthesis continues and fibres composed of fibroblasts and collagen become longitudinally oriented and progressively stronger.

When extrinsic healing predominates, adhesions between the tendon and its surrounding tissues are inevitable. Healing that is largely based on intrinsic cellular activity will result in fewer, less dense adhesions.

There is strong scientific documentation that early post operative motion enhances tendon healing by promoting synovial diffusion of nutrients, increasing DNA contents and collagen production and stimulating the maturation and strength of tendon wound simultaneous with remodelling of tendon scar[8].

It has now been well demonstrated that the application of early passive motion stress to repaired tendons leads to more rapid recovery of tensile strength, fewer adhesions, improved excursion, better nutrition and minimum repair site deformation when compared with immobilised tendons[9].

The most effective method of returning strength and excursion to repaired tendons involves use of strong, resistant suture techniques followed by frequent application of controlled motion stress.

ANATOMIC NOMENCLATURE OF FLEXOR TENDON INJURIES

According to First Congress of International Federation of Societies for Surgery of Hand, flexor tendon injuries are divided into 5 zones.

FINGERS

Zone 1 – Area traversed by FDP distal to insertion of FDS

Zone 2 - From first annular ligament to insertion of FDS.

It is subdivided in to distal, middle and proximal components

Distal : Extends from insertion of FDS to proximal end of A3 pulley

Middle : Proximal end of A3 pulley to distal end of A2 pulley

Proximal : Distal end of A2 pulley to proximal end of A2 pulley

Zone 3 – From distal end of carpal tunnel to first annular ligament

Zone 4 – Beneath carpal tunnel

Zone 5 – Proximal to carpal tunnel to musculo tendinous junction.

THUMB

Zone T1 - Area traversed by FPL distal to interphalangeal joints

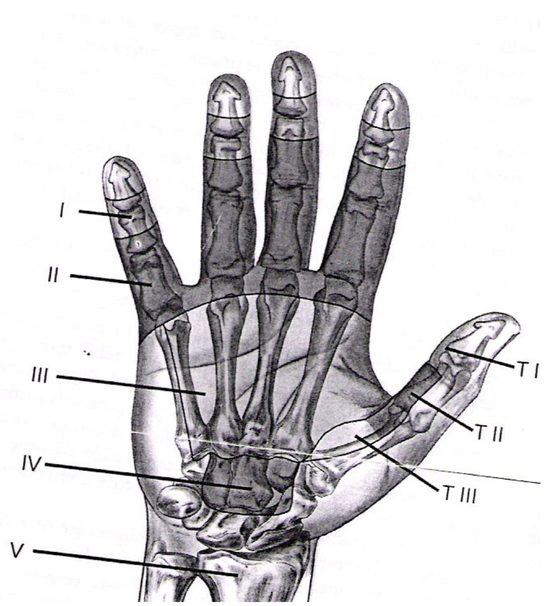
Zone T2 - From annular ligament to interphalangeal joint

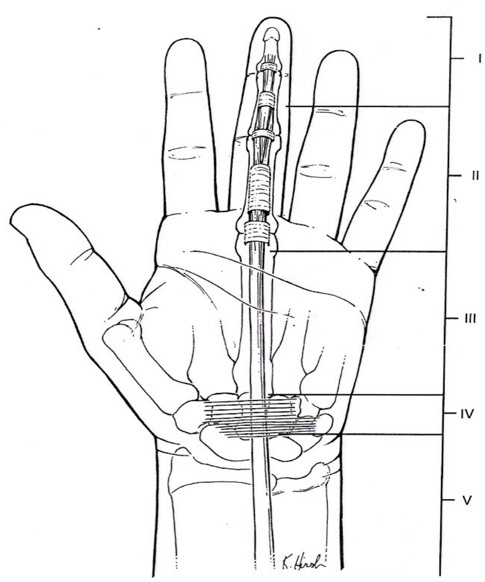
Zone T3 - The thenar eminence

Zone T4 - Beneath Carpal tunnel

Zone T5 - Proximal to carpal tunnel.

ANATOMICAL ZONES OF FLEXOR TENDONS





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The type of wounds associated with tendon injuries can be classified into the following four groups.

Group 1 - A clean wound with isolated tendon injury

Group 2 - A clean wound with tendon and associated neurovascular injury

Group 3 - Tendon injury with associated bone or joint injury

Group 4 - Tendon injury with associated skin loss, neurovascular injures, bone & joint injury.

The type of injury (Sharp, blunt, crush ,avulsion), the circumstances at time of injury (at home, at work, at street, or in field) nature of wound (tidy or untidy, undamaged or crushed skin) site & extent of tendon injury and concomitant injuries influence the decision for primary or secondary repair of involved tendons.

With respect to timing of tendon repair from time of injury, tenorrhaphy can be classified as follows :

Primary Tendon repair	-	Within 24 hours
Delayed primary tendon repair	-	24 hours – 2 weeks
Early secondary tendon repair	-	2 weeks – 5 weeks.
Late secondary tendon repair	-	After 5 weeks.

When treated more than five weeks after injury, the cut muscle tendon unit has lost tone and elasticity and has shortened and thickened. The delay period is more critical if the laceration is proximal to the wrist joints. Elasticity of proximal muscle tendon units is lost. Thus zone 5 injures should be repaired within 4 weeks whenever possible.

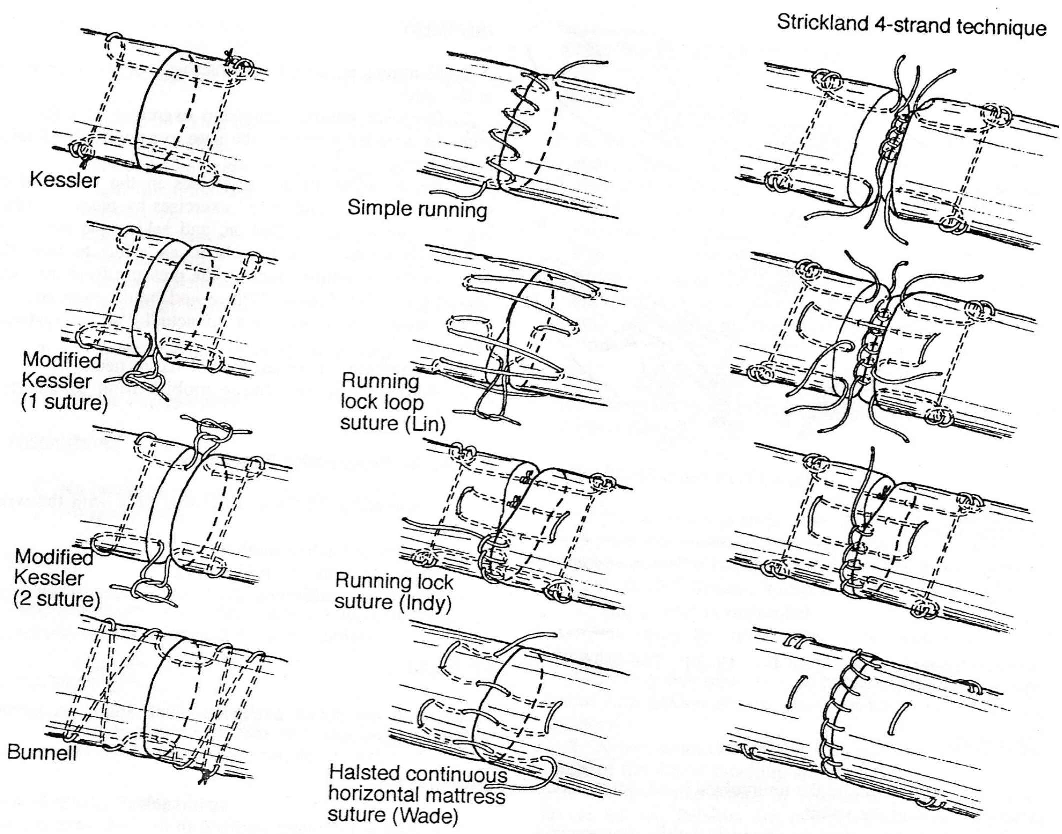
TECHNIQUES OF TENDON REPAIR

There have been innumerable techniques of tendon sutures. Essentially it included a core suture which is placed on dorsal half of the tendon and a peripheral epitendinous suture.

Some of the named techniques for the core sutures are :

1) Modified Kessler – Mason Suture
2) Kessler Stitch
3) Tajima Stitch
4) Bunnell Stitch
5) Tsuge stitch
6) Double grasping suture (Taras)
7) 4 - Stranded Strickland suture
8) 6 - Stranded Sandow suture
9) 6 - Stranded Lim & Tsai suture.

Various Techniques of Tendon Suturing



Numerous methods of tendon suture have been advocated in an effort to satisfy the ideal characteristics of primary suture of acutely divided flexor tendons.

1) Easy suture placements

2) Secure suture knots

3) Smooth junction of tendon ends

4) Minimal gaping potential at repair site

5) Minimal interference with tendon vascularity

6) Sufficient strength throughout healing to permit the application of early motion stress to the tendon.

The characteristics and performance of differing flexor tendon repairs would lead to following general conclusions.

1) The strength of flexor tendon repair is roughly proportional to the number of suture strands that cross the repair site.

2) Locking loops contribute modestly to strength but may collapse and lead to gapping at moderate loads.

3) Repairs usually rupture at suture knots.

4) Each progressively larger suture calibre increases the repair strength significantly.

5) Synthetic 3-0 (or) 4-0 braided sutures are probably the best for flexor tendon repair, although a polyfilament ensheathed by caprolactan (Supramid) was found to be the strongest.

6) The fewer suture knots, the better.

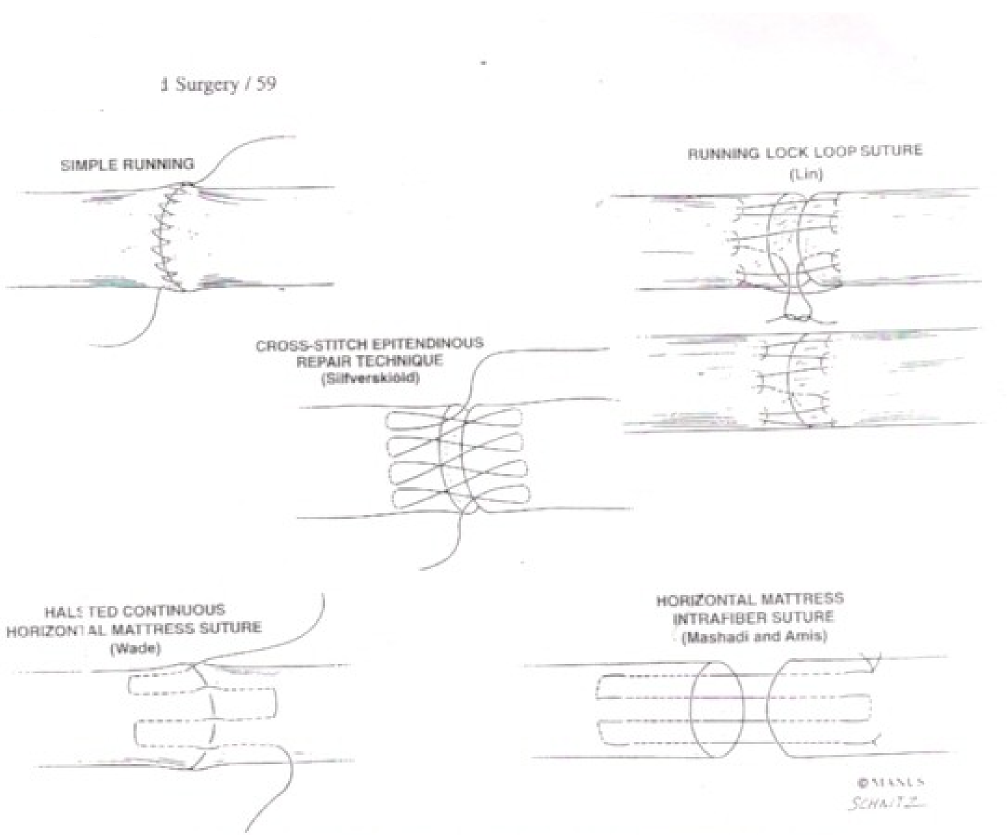
7) Equal tension should exist across all suture strands to prevent differential loading,which weakens the repair.

PERIPHERAL EPITENDINOUS SUTURES

Most studies have indicated that gapping at the repair site becomes the weakest part of the tendon, unfavourably alters tendon mechanics, and may attract adhesions resulting in decreased tendon excursion.

The importance of the addition of a peripheral circumferential epitendinous suture to a tendon repair has been demonstrated by the findings that such suture may provide anywhere from a 10% - 50% increase in flexor tendon repair strength and a significant reduction in gapping between the tendon ends. The running lock stitch, horizontal mattress, epitenon / intra fibre, and cross stitch methods have been shown to be the strongest of peripheral suture techniques

Methods of peripheral epidendinous suture techniques.



TENDON SUTRUE MATERIALS

A polyfilament ensheathed by caprolactan (Supramid) was found to be the most advantageous. Nylon and polypropylene monofilament have lower tensile strength and increased elasticity.

A 3-0, 4-0 braided polyester suture are preferred because of their ease of placements, adequate strength and minimum extension at failure.

Curved, atraumatic needles are usually preferred to avoid inflicting further damage to the severed tendon.

REHABILITATION AFTER FLEXOR TENDON REPAIRS

Many techniques and modifications of techniques have been advanced in an effort to mechanically alter the normal biologic sequence of tissue healing and modify the formation of adhesions around a tendon repair. Applying early post-repair motion stress to repaired flexor tendons has been shown to be beneficial for

i) More rapid recovery of tensile strength

ii) Fewer adhesions

iii) Improved tendon excursion

iv) Minimal repair site deformation

EARLY POST REPAIR MOTION STRESS PROTOCOLS :

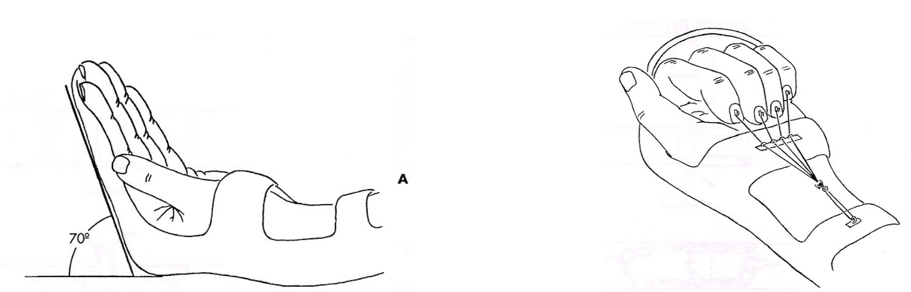
Early mobilisation protocols generally full into three categories

1) Active extension with rubber band flexion
2) Controlled passive motion
3) Controlled active motion

ACTIVE EXTENSION – RUBBER BAND

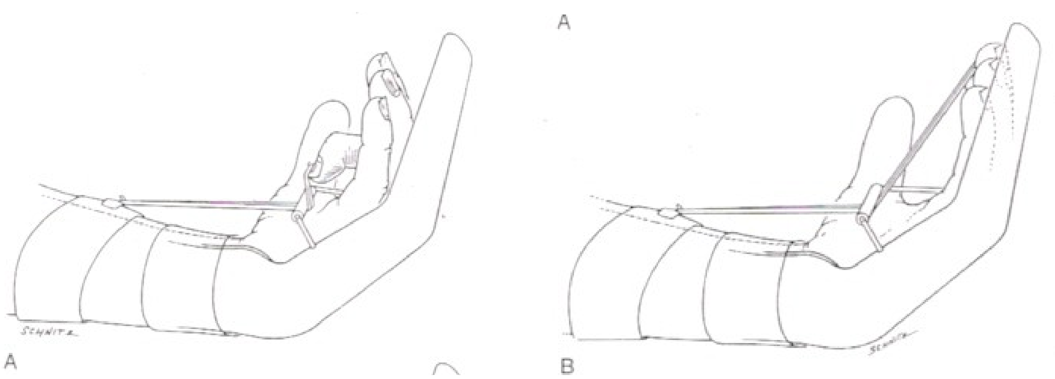
Harold Kleinert developed and practiced a technique in late 1950. His protocol[11] consisted of a splint that was applied posteriorly while maintaining the wrist in flexed attitude. The finger that had incurred flexor tendon interruption was maintained in a flexed attitude by an elastic band attached to the finger nail and to the dressing at wrist level. The patient was permitted to actively extend the finger within the limits of splint with the elastic band passively returning the finger to a partially flexed attitude.

Original Kleinert's Rubber Band Flexion Splint



The original controlled motion protocol recommended by Kleinert et al has been modified by decreasing flexion at wrist and increasing flexion at MP joints. In addition, almost all recent modifications of the active digital extension and rubber band flexion method of Kleinert incorporate a distal palmar bar that allows the rubber band to have a more direct approach to the terminal digit from the distal palmar and results in nearly complete interdigital flexion during rubber band contraction.

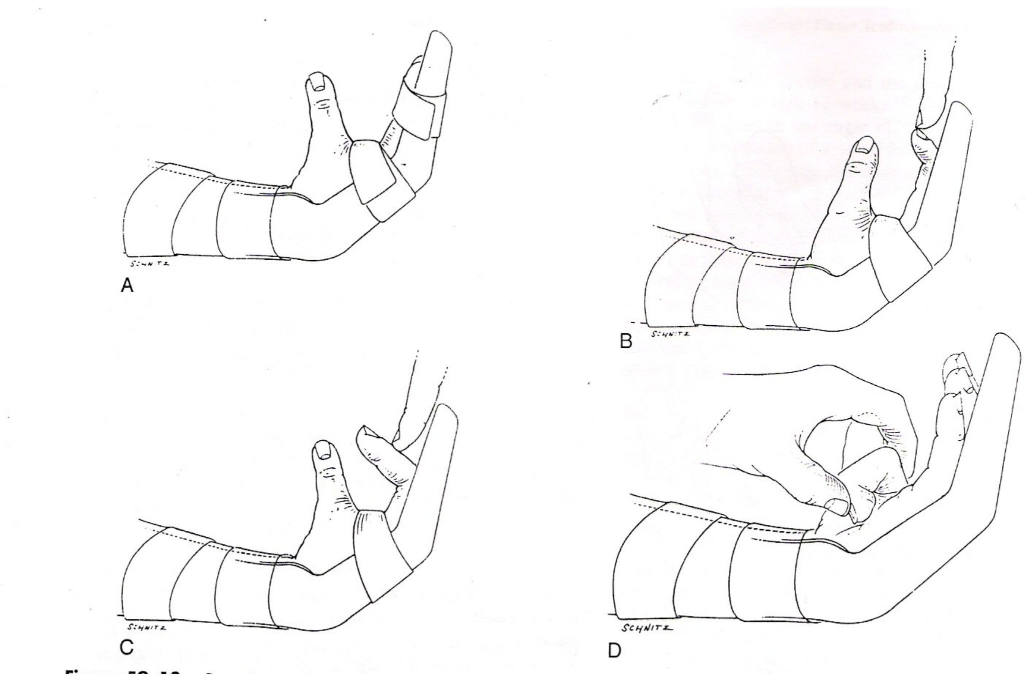
Modified Kleinert's Rubber Band Flexion Splint



CONTROLLED PASSIVE MOTION METHOD

The controlled passive motion method has also evolved into protocols that encourage more passive interdigital motion that was originally recommended by Duran and Houser. Proponents of controlled passive motion protocol contend that it is less likely to result in flexion contractures than the rubber band flexion / active extension method. In addition, the involved digit may be better protected between periods of exercise.

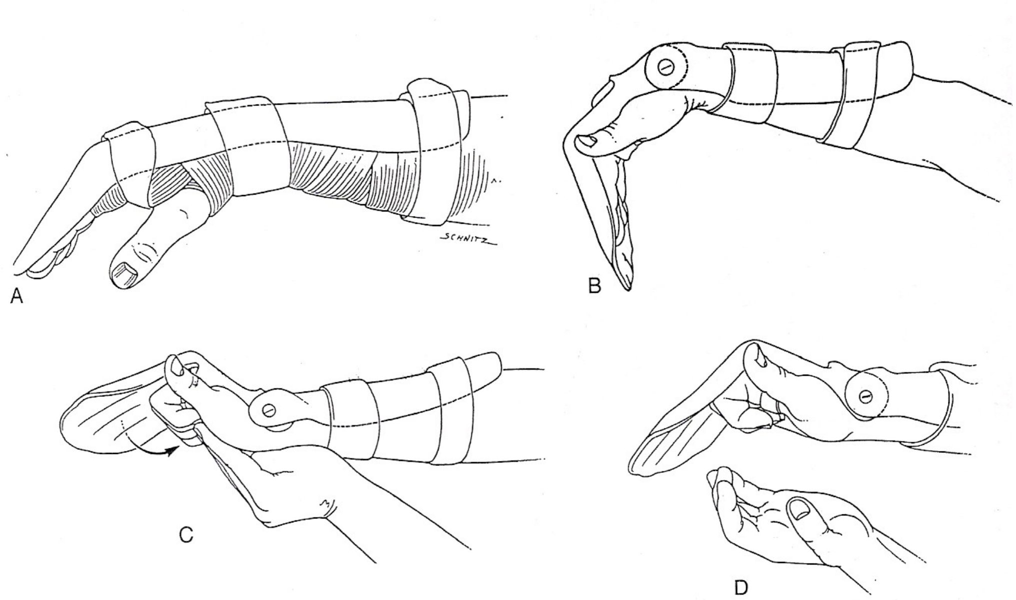
Controlled Passive Motion Protocol of Duran And Houser



CONTROLLED ACTIVE MOTION METHOD

In an attempt to obtain better functional recovery, progressively more hand surgeons have begun to use various methods of active mobilisation. It has already been demonstrated that four & six strand flexor tendon repair methods combined with strong peripheral epitendinous sutures should be sufficient strong to withstand light active forces throughout healing. Those in favour of early active mobilisation generally believe that this technique allows greater gliding of healing tendon, reducing adhesions and in turn may allow improved return of function when compared with passive motion protocols.

Controlled Active Motion Protocol of Strickland and Cannon



COMMON FEATURES OF ALL METHODS

In almost all flexor post-repair mobilisation protocols, aggressive use of hand is not allowed until after eighth post operative week, at which points strengthening activities are progressively increased. These programs are not usually appreciable to children below 10 years and should not be used for any patients deemed unreliable by surgeon and therapist.

FUNCTIONAL OUTCOMES – EVALUATION SYSTEMS

There are many methods of evaluation of results of flexor tendon repair

1) **Boyes** method measures the distance from digital pulp to distal palmar crease during maximal finger flexion.

2) **Louisville** system measures pulp to palm distance and any extension deficit at DIP, PIP, MCP joints.

3) **Buck – Gramco** system measures pulp to palm distance, the extension deficit and composite distal joints flexion.

BUCK – GRAMCO SYSTEM

A) Distance of finger pulp to distal palmar crease and composite flexion

0-2.5cms / $\geq 200^{o}$ - 6 points

2.5 – 4cms / $\geq 180^{o}$ - 4 points

4 – 6 cms / $\geq 150^{o}$ - 2 points

6 cms / $\leq 150^{o}$ - 0 points

B) Extension Deficit

$0^{\circ} - 30^{\circ}$	-	3 points
$31^{\circ} - 50^{\circ}$	-	2 points
$51^{\circ} - 70^{\circ}$	-	1 point
$\geq 70^{\circ}$	-	0 point

C) TAM

$\geq 160^{\circ}$	-	6 points
$\geq 140^{\circ}$	-	4 points
$\geq 120^{\circ}$	-	2 points
$< 120^{\circ}$	-	0 points

Score :

14-15 points	-	Excellent
11-13 points	-	Good
7-10 points	-	Fair
0 – 6 points	-	Poor

4) American society for surgery of hand **(ASSH)** devised the total active motion scale

(TAM) to assess digital motion after flexor tendon repair in which any extension lag at DIP, PIP, MCP joints is subtracted from total active flexion.

TAM = (DIP + PIP + MCP) flexion° – Extension Lag°

5) **Strickland** noted that MCP flexion is dependent on intrinsic muscle function and is rarely affected by flexor tendon surgery. He recommended exclusion of MCP joint movement from assessment.

Strickland adjusted TAM

$$= \frac{(\text{DIP} + \text{PIP Flexion}^\circ) - (\text{DIP} + \text{PIP extension lag}^\circ)}{175} \times 100$$

Results were graded as follows :

Excellent - TAM is 75% - 100%

Good - TAM is 50% - 74%

Fair - TAM is 25% - 49%

Excellent - TAM is < 25%.

MATERIALS AND METHODS

The study was conducted in **Dept. of Plastic and Reconstructive Surgery, Madras Medical College and Govt. General Hospital from July 2003 to August 2005 .**

A total of **20** patients **(18 male, 2 female)** were included in the study.

INCLUSION CRITERIA

- Adult patients with flexor tendon injuries in Zone V

EXCLUSION CRITERIA

- Children with flexor tendon injuries in Zone V
- Patients with flexor tendon injuries in multiple zones
- Patients with flexor tendon injuries with concomitant bony injuries and skin loss
- Patients with both flexor and extensor tendon injuries.

TYPE OF WOUNDS

Group	No. of Patients
Group 1	1
Group 2	19

MODE OF INJURY

Injury	No. of Patients
Road Traffic Accident	7
Assault by sharp weapon	6
Accidental injury at work	6
Intentional	1

SIDE OF INJURY

Right	Left	Both
16	3	1

METHODS

All patients were operated under suitable anaesthesia - axillary (or) supraclavicular blocks (or) general anaesthesia.

Type of Repair	No. of Patients
Primary Tendon Repair	17
Early secondary repair	3

2 cases of secondary repair were referred to us after skin suturing elsewhere and 1 case had primary management for head injury and hence primary tendon repair was deferred.

A total of 120 tendons were repaired which included,

1) 58 flexor digitorum superficialis

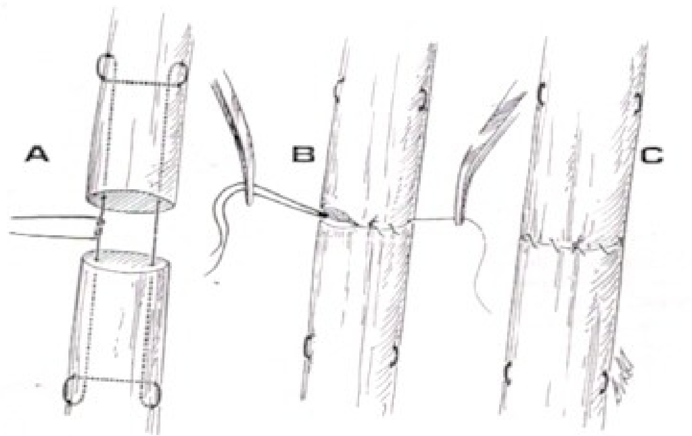
2) 52 flexor digitorum profundus

3) 10 flexor pollicis longus

TYPE OF TENDON SUTURE

After adequate exposure, we repaired the flexor tendons in Zone V with modified Kessler- Mason core suture using 3-0 prolene and a peripheral continuous epitendinous suture with 6-0 prolene (Atraumatic curved needles)

Flexor Tendon Repair with Core and Epitendinous Suture



Atraumatic handling of tendons with hypodermic needles and skin hooks were strictly adhered to[16].

Injured median and ulnar nerves were repaired with 6-0 prolene epineural sutures.

Vessel anastamosis were performed with 7-0 prolene. We repair any one vessel if both major vessels are injured.

IMMOBILISATION :

Post operatively hand was immobolised in a dorsal below elbow POP slab, that extends 3cm beyond finger tips, keeping the wrist in 30-45° flexion, MP joints 60-75° flexion and IP joints neutral.

POST OPERATIVE PHYSIOTHERAPY PROTOCOL

We followed early mobilisation protocol by using a modification of Kleinert's elastic band traction.

48 hrs – 3 weeks

After 48 hours of tendon repair, elastic band traction is applied to the finger nails through hooks[3] from 3-4 inches proximal to wrist on volar aspect of forearm dressing. The elastic band is routed through a mid palmar pulley in form of a safety pin. (like the modified Kleinert Brooke Army Splint)

The elastic band applied to finger nails produces passive flexion of finger at IP joints. The incorporation of palmar pulley produces complete composite digital flexion. The patient actively extends the fingers against rubber band traction (Active Extension - Rubber Band Flexion Method) within the confines of the splint. Rubber band traction to the thumb is given from nail hook to ulnar border of the palm separately.

The patient is advised to start with 10-12 movements per hour of this regimen. Active extension stops are a point which produces pain. Tension in rubber band is adjusted so that full extension atleast by 5th POD within the limits of splint is possible, for fear of developing flexion contractures.

The patient is constantly monitored for tension in the elastic band and development of features of flexion contracture. If features are present gentle passive extension exercises of IP joints are instituted by physiotherapist with MP joints in full flexion.

This regimen is followed for a period of 3 weeks.

3-6 Weeks

The dorsal POP is removed and wrist block is provided to avoid hyperextension at wrist.

Gentle active assisted flexion exercises are commenced and patient is encouraged to do full active extension at IP and MP joints with wrist in neutral.

7-10 Weeks

Mild restrictive exercises are begun from 7th week and light sustained grip activities by 10 weeks.

11-12 weeks

Moderate to heavy restrictive exercises are commenced to increase grip strength.

For patient with ulnar and median nerve injuries which were repaired simultaneous, claw correcting splints and short thumb abduction splints are given after 3 weeks of initial elastic band traction regimen and followed up with electrical stimulation for intrinsic hand muscles.

Follow-up.

Ranged from 3 – 14 months. The follow-up of patients who had primary tenorrhaphy was between 3-12 months while the follow-up for patients who had secondary tenorrhaphy was between 5 – 14 months.

The functional outcome was assessed after 12 weeks and thereafter

We adopt Louisville Grading system for assessing digital motion and IP flexion degree for thumb.

FINGERS

Flexion

Grade I - If pulp touched (or) lacked not more than 1 cm from distal palmar crease

Grade II - If pulp lacked not more than 1.5 cm from distal palmar crease.

Grade III - If pulp lacked not more than 3 cm of distal palmar crease

Grade IV - Poor result than Grade I.

EXTENSION

Grade I - If extension deficit was less than 15º

Grade II - If extension deficit was between 15º – 30º

Grade III - If extension deficit was 30º-50º

RESULTS

Excellent	-	If both deficits were Grade I
Good	-	If both deficits were Grade II
Fair	-	If both deficits were at worse Grade III
Poor	-	If either deficits was worse than Grade III

THUMB

Flexion of thumb at IP Joint

$$\text{Flexion \%} = \frac{\text{IP Flexion affected thumb}}{\text{IP flexion normal thumb}} \times 100$$

RESULTS

Excellent if flexion % is 75% - 100%

Good if flexion % is 50% - 74%

Fair if flexion % is 25-49%

Poor if flexion % is < 24%

As suggested by Strickland, the digital flexor tendons do not have a direct action on empty joint which is primarily flexed by the intrinsic muscles. Hence during assessment the MP joints were passively kept in flexion while actively measuring the flexion and extension grades at IP joints has enumerated above.

OBSERVATION AND RESULTS

17 patients who had primary tendon repair were followed up for a mean period of **5** months and **3** patients of early secondary tenorrhaphy were followed up for a mean period of **10** months.

All the results were graded at **12** weeks after injury and thereafter.

Of the **17** patients with primary tenorrhaphy, digital flexion was graded **excellent in 7 patients, good in 7 patient, fair in 3 patients.**

Thumb flexion was graded **excellent in 8 patients and good in 2 patients.**

FUNCTIONAL OUTCOME AFTER PRIMARY TENORRHAPHY FOR DIGITAL FLEXOR TENDONS

Sl.No.	Function	No. of Patients.
1.	Excellent	7
2.	Good	7
3.	Fair	3
4.	Poor	-

Of **3** patients with early secondary tenorrhaphy, digital function was graded **excellent in 2** patients and **fair in 1** patient.

FUNCTIONAL OUTCOME IN SECONDARY TENORRHAPHY FOR DIGITAL FLEXOR TENDONS

Sl.No.	Function	No. of Patients.

1.	Excellent	2
2.	Good	0
3.	Fair	1
4.	Poor	0

Totally digital flexion function was excellent in 45% / Good in 35% / Fair in 20%.

TOTAL FUNCTIONAL OUTCOME IN 20 PATIENTS

Sl.No.	Function	No. of Patients	Percentage
1.	Excellent	9	45%
2.	Good	7	35%
3.	Fair	4	20%
4.	Poor	-	-

None were rated poor.

There were no tendon ruptures in our study during the period of follow-up.

Flexion contracture of DIP joint was encountered in 1 patient which was picked up early and treated with passive stretching exercises and night splints.

Tenolysis was required in 2 patients out of 20.

There was independent FDP and FDS actions in 9 out of 20 patients.

In one patient (Group I injury) who showed good range of motion even after 8^{th} week, restrictive exercises were delayed by 2 weeks for fear of late tendon rupture as suggested by

Schneider. The patient faired well without any complications on further follow-up.

In a patient who had only fair range of movement after early secondary tendon repair, in which there was extension deficit due to flexor tendon shortening, he was advised dynamic extension out trigger splint but he lost follow up afterwards.

DISCUSSION

With respect to the published articles, we tried to evaluate the functional outcomes of flexor tendon repair in Zone V rehabilitated with modified Kleinert's rubber band traction regime in our study.

RANGE OF MOTION ACHIEVED

Charles Puckett et al[1] in 1984 had achieved good to excellent range of motion using Kleinert's type of dynamic splint and early mobolisation protocol in 97% of 37 patients who were followed up for 40 months.

Mark Edinburg et al[6] in 1987 used a modified Kleinert's splint for early post operation mobilistion of 20 cases of Zone V flexor tendon injuries and achieved good to excellent results in 55% of the cases after a mean period of 4 months.

Raymond Stefanich et al[17] in 1992 reviewed the results of 23 flexor tendon lacerations of Zone V rehabilitated by Kleinert's protocol after 46 months of trauma and found good to excellent range of digital flexion in 70% of the cases.

Yii N.W, Urban et al[21] in 1998, in their prospective study of 52 patients with Zone V flexor tendon injuries rehabilitated with controlled active motion, found digital range of motion to be good to excellent in 90% of cases.

In our study of 20 patients of Zone V flexor tendon injuries , we achieved good to excellent results in 80% of cases using modified Kleinert's protocol.

GOOD TO EXCELLENT RESULTS ACHIEVED IN DIGITAL RANGE OF MOTION

Name of the Authors	Percentage
Charles Puckett (1984)	97%
Mark Edinburg (1987)	55%
Raymond Stefanich (1992)	70%
Yii N.W, Urban (1998)	90%
STUDY	**80%**

The series with Charles Puckett did not take into account any extension deficit and Mark Edinburg's results were evaluated by the more complex Buck-Gramcko system.

INDEPENDENT FDS / FDP ACTION

Raymond Stefanich[17] in 1992 in their review of 23 patients rehabilitated with Kleinert's Protocol found independent FDS & FDP actions only in 7 patients (about 31% of cases).

Mark Edinburg et al[6] & Charles Puckett et al[1] did not study the individual FDP and FDS actions in their series.

Yii N.W, Urban et al[21] in 1998 in their study of 161, digits with one or both tendons injured rehabilitated with controlled active mobilisation found independent FDS & FDP actions in 66% of cases.

In our study of 20 patients with 58 digits of one or both injured tendons, rehabilitated with modified Kleinert's early mobilisation regime, we found independent FDS & FDP actions in 45% of cases.

INDEPENDENT FDP & FDS ACTION

Name of the Authors	Percentage
Raymond Stefanich (1992)	31%
Yii N.W, Urban (1998)	66%
STUDY	**45%**

The superiority of modified Kleinert's protocol over the original Kleinert's protocol, in Zone V injuries with respect to achievements of independent FDS & FDP action are well highlighted.

COMPLICATIONS

	No. of tendon Ruptures	Tenolysis
Charles Puckett	-	-
Raymond	2	4
STUDY	**-**	**2**

There are many modifications of Kleinert's splint cited in literature.

i) Slattery & McGrouther[18] using a distal palmar bar to improve passive DIP flexion.

ii) Edinburg et al[6] using a Steinman pin incorporated into the POP acting as a distal palmar pulley.

iii) Knight S.L[12]. rerouting the elastic band from finger tip on to the dorsum of splint at MP level to facilitate more DIP joint flexion.

But we have found in our study that our method of using a safely pin at mid palmar level as a modification of Kleinert's splint to facilitate early mobilisation for repaired flexor tendon injuries in Zone V has been simple, cost effective, safe and has yielded results on par to that quoted in literature.

CONCLUSION

Improved understanding of the physiologic benefits of early active tension at a tendon repair site over passive motion and immobilisation, the development of stronger suture repair techniques and improvements in post operative management techniques have led to an increased acceptance of early mobilisation in management of repaired flexor tendons.

With a simple and cost effective modified Kleinert's rubber band traction early mobilisation protocol we have achieved satisfactory results for repaired digital flexor tendon in Zone V in the selected group of patients in our setup.

Nevertheless the overall hand function after such volar wrist lacerations after primary repair of injured structures depends on success of nerve repairs even though the range of motion of repaired tendons is satisfactory.

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PROFORMA

EVALUATION OF MODIFIED KLEINERT'S TRACTION EARLY MOBILISATION SCHEDULE FOR FLEXOR TENDON INJURIES

IN ZONE V

Name : Age / Sex : PS No. :

Address : Occupation :

Dominant Hand :

Side and nature of Injury :

Concomitant Injuries (if any) :

Time of Surgery since injury :

Type of Anaesthesia :

PER OPERATIVE FINDINGS AND OPERATIVE PROCEDURE :

Sl.No.	***Structures Injured***	**Method of Repair**	**Suture**

PHYSIOTHERAPY SCHEDULE

Till 3 weeks

4 – 6 weeks

7 – 10 weeks

11 – 12 weeks

> 3 Months

EVALUATION OF POST-OPERATIVE TENDON FUNCTION

	4 weeks	**8 weeks**	**12 weeks**	**6 months**	**> 6 months**
Thumb					
Index					
Middle					
Ring					
Little					

Overall result of Tendon function achieved :

Complications (if any) :

Secondary Procedures (if any) :

INDEX FOR EVALUATION OF RESULTS :

FLEXION :

Grade I	:	If the pulp touched (or) lacked not more than 1 cm from distal palmar crease
Grade II	:	If the pulp lacked not more than 1.5 cm from the distal palmar crease
Grade III	:	If the pulp lacked not more than 3 cm of the distal palmar crease
Grade IV	:	Poor result than Grade III

EXTENSION

Grade I	:	If extension deficit was less than 15 degrees
Grade II	:	If extension deficit was more than 15 degrees but less than 30 degrees.
Grade III	:	If extension deficit was more than 30 degree but less than 50 degrees.

RESULTS

Excellent	:	If both deficits were Grade I
Good	:	If both deficits were Grade II
Fair	:	If both deficits were at worse Grade III
Poor	:	If either deficit was worse than Grade III

Thumb
Flexion of thumb at IP Joint

$$\text{Flexion \%} = \frac{\text{IP Flexion affected thhumb}}{\text{IP flexion normal thumb}} \times 100$$

RESULTS
Excellent if flexion % is 75% - 100%
Good if flexion % is 50% - 74%
Fair if flexion % is 25-49%
Poor if flexion % is < 24%